AD-A046 455 GOETTINGEN UNIV (WEST GERMANY) INSTITUT FUER PHYSIKA--ETC F/G 21/2
INFLUENCE OF VARIOUS PARAMETERS ON INITIATION, STABILITY AND LI--ETC(U)
JUL 77 W JOST, H G WAGNER AFOSR-73-2541
UNCLASSIFIED SCIENTIFIC-4 AFOSR-TR-77-1279 NL

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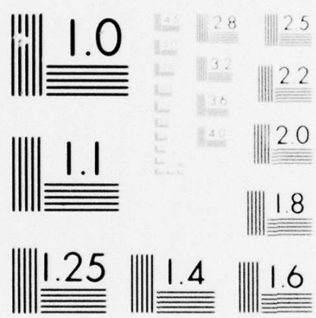

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AFOSR-TR- 77-1279

Contract/Grant Number AFSOR 73-2541

AD A046455

INFLUENCE OF VARIOUS PARAMETERS ON INITIATION, STABILITY AND LIMITS OF DETONATIONS

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31 July 1977

See 1473

Interim Scientific Report, 76 June 01 - 77 May 31
(Scientific Report No. 4)

Approved for public release; distribution unlimited.

Prepared for USAF Office of Scientific Research
Buildung 410, AFB D.C. 20332

and

EUROPEAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT
London, England

INTRODUCTION

In previous experiments various grids have been placed into the path of spherical flames in order to increase the flame speed by small scale turbulence in the unburned gas, generated by the flame propagation process. For hydrocarbon air mixtures the flame acceleration α went up to about a factor of 6. (Fig. 1) Only in case of oxygen enriched mixtures of C_2H_2 and C_2H_4 with air instantaneous transition to detonation results upon emergence from the grid.

The question arises whether there are other possibilities to increase for hydrocarbon air mixtures further, even if the effect is only a local one.

From Wheelers experiments it is known, that orifices in the flame path can strongly accelerate flames. It is also well known, that obstacles can accelerate the establishment of detonation.

Here we will describe some experiments, which have been performed in order to obtain some quantitative data about the influence of orifices on flame propagation and flame, generated previous in partly confined systems.

EXPERIMENTAL

The flame tubes are shown in Fig. 2. Length and diameter of the plexiglass ring metall tubes are shown, also the diameters of the orifices. The tubes were filled with stoichiometric C_2H_4-air mixtures and ignited by a weak spark. Pressure could be recorded on both sides of the orifice

plate. Smear camera and movie pictures could be taken and the passage of the flame could be checked by conductivity measurements with electrodes down stream of the orifice.

SMEAR CAMERA RESULTS

A typical streak record of the transmission of the flame through the orifice plate is shown in Fig. 3 for a special set of R_1, R_2 and d_O. In the ignition tube the flame propagates towards the orifice with a speed of about 20 m/sec. Downstream of the orifice the flame propagates much faster, for a short distance in two directions. Further downstream the flame decelerates again, as is to be espected.

The ratio of the flame speed on both sides of the orifice is shown as a function of the orifice area divided by the area of the ignition tube. (Fig. 4) One can see that really high values can be obtained locally. The data for the grids, used in previous measurements fit well into this curve. It should also be noted that orifices of very different shapes as well as obstacles give the same results. It should be noted here that towards small orifices the flame speeds in the ignition tube are lower. If one therefore would plot the flame speeds downstream of the orifice as a function of $\frac{F}{F}$ the maximum of the curve is shifted towards the right side. Grids mounted on the orifice did not cause pronounced additional flame acceleration.

PRESSURE MEASUREMTNS

The rapid change of flame velocity is connected with a pressure increase in the downstream tube and the Fig. 5 shows pressure records on both sides of the orifice for various orifice diameters. The upper trace corresponds to the pressure downstream of the orifice. Both traces start at the same instant, have the same sweeptime and the same sensitivity. The pressure in the ignition tube (lower trace) shows a slow rise, which for small orifice diameters remains constant for some time and then decreases when the burned gas escapes.

The pressure downstream shows a rather rapid rise after a certain time t_4 characterizing reignition downstream of the orifice. As the orifice diameter increases the upstream pressure decreases due to the venting of the unburned gas. The time t_4 decreases and the peak downstream pressure increases up to a certain nozzle size. This pressure puls is also recorded almost simultaneously upstream of the orifice due to the back flow. Towards still larger orifices pressures decrease further. t_4 the time of appearance of the peak downstream pressure, which characterizes the reignition time for smaller orifices, is shown in Fig. 6. For the same tube length t_4 is the same for both tubes indicating that the volume of the upstream tube have no influence on t_4. For orifice diameters below 8 mm t_4 approaches infinity marking the failure of combustion through orifices below 5 to 6 mm Ø.

The maximum pressures obtained downstream are shown in Fig. 7 as function of the area ratio. These curves are similar in shape to the $\alpha = \alpha\ (\frac{F}{F_o})$ curves and the maximum

over-pressure arises around an open area of about 30 % indicating optimum conditions for flame acceleration.

This Fig. shows that another parameter of the system which has strong influence on the maximum pressure is the diameter of the outside tube. The maximum is obtained for $R_2 \simeq 2 R_1$. For larger R_2 the peak pressure decreases.

How can these relatively high local flame speeds and pressures be explained. The sequence of events which we could see already on Fig. 2 is put together from movie pictures in Fig. 8. Frames 1 to 7 show the flame moving towards the orifice plate in the upstream section. During this process unburned gas flows as a jet through the orifice where it generates turbulence and a recirculation zone. In 8 and 9 the flame arrives at the orifice plate and from that moment a hot jet follows with a velocity that is higher than that of the cold gas jet. This contact zone may propagate like a plume as observed with flames penetrating into the open. In some cases the burning gas pocket at the head of the luminous jet is observable.

Frame 10 clearly shows a luminous spot appearing nearly 3tube diameters or 10 orifice diameters ($\sim$20 cm) downstream. In frame 11, taken 2 msec later, a large volume of gas reacted blowing burned or burning gas into the ignition tube. Only the recirculation zone is still unburned. It is consumed 2 msec later in frame 11. The combustion in frame 10 would correspond to a flame speed of about 100 msec or even more, towards the closed and of the system, i. e. directed towards the ignition tube. This is in agreement with Fig. 2.

This rapidity of the combustion process cannot be due to turbulence alone. It brings about the important role of turbulent mixing between the hot product gas in the jet with the already turbulent unburned mixture downstream.

For a 20 mm Ø orifice, ignition tube of 40 mm Ø and a downstream tube of 80 mm Ø, that means for optimum conditions, the flow situation for an unconfined jet is shown in Fig. 9. The lines where velocity is down to 10 % an concentration down to 50 % of the value on the jet axis are given. In reality the jet is confined under these circumstances, therefore the entrainment of cold mixture is limited.

Ignition starts about 10 orifice diameters downstream. Assuming the gas in the $c_a/2$ cone to be mixed completely with the hot gas jet the volume would have an average temperature of about 400°C and the concentration of the unburned gas would be reduced by about 20 % of its initial concentration. Radicals are also present from the burned gas. In reality the gas is not completely mixed and in the centerline, where explosion starts the temperature at 10 d is still, without flame above 1000 K. It takes about $\sim 10^{-4}$ sec until the front of the hot jet has reached that explosion center. There are definitely zones in which conditions for self ignition are better than estimated above for the volume. That means, a good deal of the gas behind the front is mixed and heated, to explode more or less ready after a certain induction time. With the film camera used we cannot distinguish between flame propagation and self ignition within that volume. The pictures shown do not exclude that both happen at the same time.

Apparently, the case described is an optimum. The confinement is such that a jet can develop, however the amount of gas which can be entrained remains limited in the time available (10^{-4} sec !). Temperature in part of the mixed volume remains rather high. The mixture is "well prepared" for partly autoigniting or rapidly burning and the pressure release is practically one dimensional.

If the diameter of the outside tube is increased, while the other conditions are kept constant the jet will develop under less confined conditions. More combustible mixture is available for entrainment, the temperature, at least in the outer region, decreases more rapidly, thus the center part of the jet will be less influenced. Therefore, the volume of gas which is well prepared to explode becomes smaller.

This description indicates that enrichement of the air with oxygen will drastically improve the "well prepared mixture" because the jet temperature increases and at the same time the reaction proceeds faster, induction periods become much shorter and flame speeds higher.

Further increase of the tube diameter brings the system closer to a free jet and the initially exploding well prepared volume remains the same, while the total volume increases. Therefore, the pressure probe measures smaller overpressures. For large orifice diameters the velocity of the turbulent jet becomes lower, the total mass flow larger. This reignition from the tip of the jet occurs almost instantaneously as the hot burned gases are discharged from the orifice. The gradiants at the side of the jet are so small, that they no longer inhibit flame propagation. Thus a somewhat ellipsoidal flame emerges from the orifice expands and consumes all gas between it and the tube wall. This is illustrated in Fig. 10 where in contrast to Fig. 8 one cannot distinguish a distinct separation of the flame kernel from

the orifice plate. In the limit of orifice = tube diameter the flame propagates in the usual manner. When the outside tube is somewhat larger it is mainly the expanding flame area which generates some overpressure. In the limit of small orifice diameters, complete quenching can occur and no reignition happens, t_4 goes towards . The various systems applied show very similar results (Fig. 6). Comparing with the usual quenching diameters for this mixture we note that the critical orifice diameter for flame transmission is larger. This is due to the different mechanisms involved. For the quenching diameter, it is molecular diffusivity of radicals and of heat, here it is turbulent diffusivity which play the game.

In the experiments with small orifices the jets are practically free jets with high velocity and low mass flux. The gradients at the side are steep enough to quench the flames, and the time necessary to bring the temperature in the center-line below a certain value becomes very short ($< 10^{-4}$ sec). Therefore, the induction periods for self ignition become longer.

It should be noted that it is again the area of the orifice which counts to a large extent. If instead of a circular cross section a rectangular slit of the same area is used, it behaves the same way.

If the area is increased, so that the circular orifice just lets a flame pass than a rectangular slit of the same size and a slit width of < 1 mm, which is smaller than the quenching distance does the same.

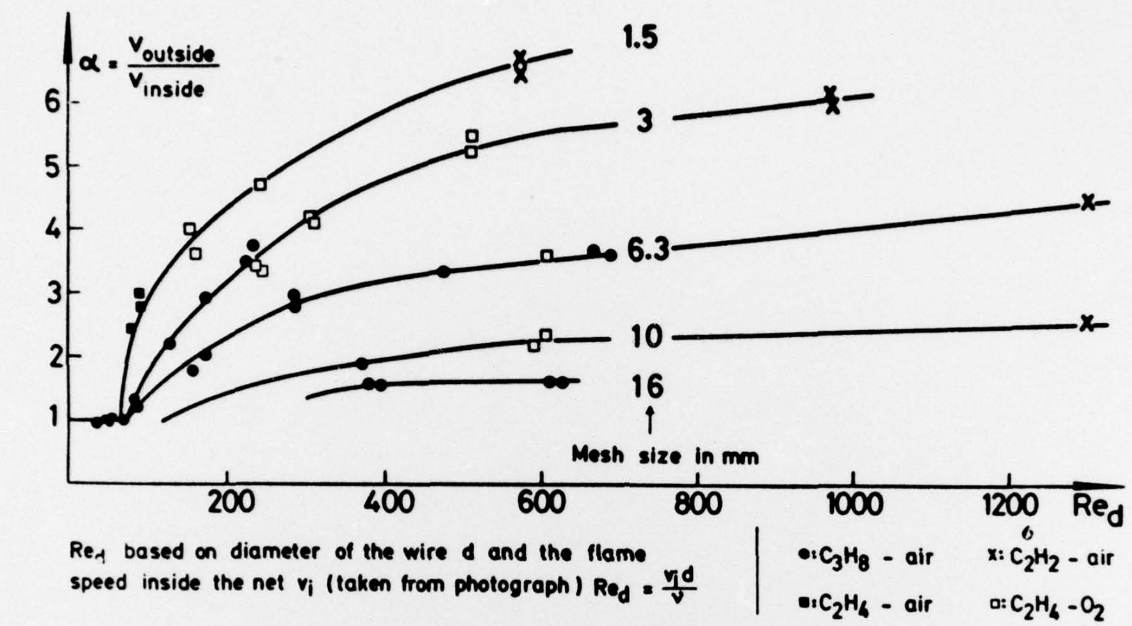
α = v_outside / v_inside
6
5
4
3
2
1
200
400
600
800
1000
1200
Re_d
1.5
3
6.3
10
16
Mesh size in mm
Re_d based on diameter of the wire d and the flame speed inside the net v_i (taken from photograph) Re_d = v_i d / ν
●: C3H8 - air
x: C2H2 - air
■: C2H4 - air
□: C2H4 - O2

Fig. 1

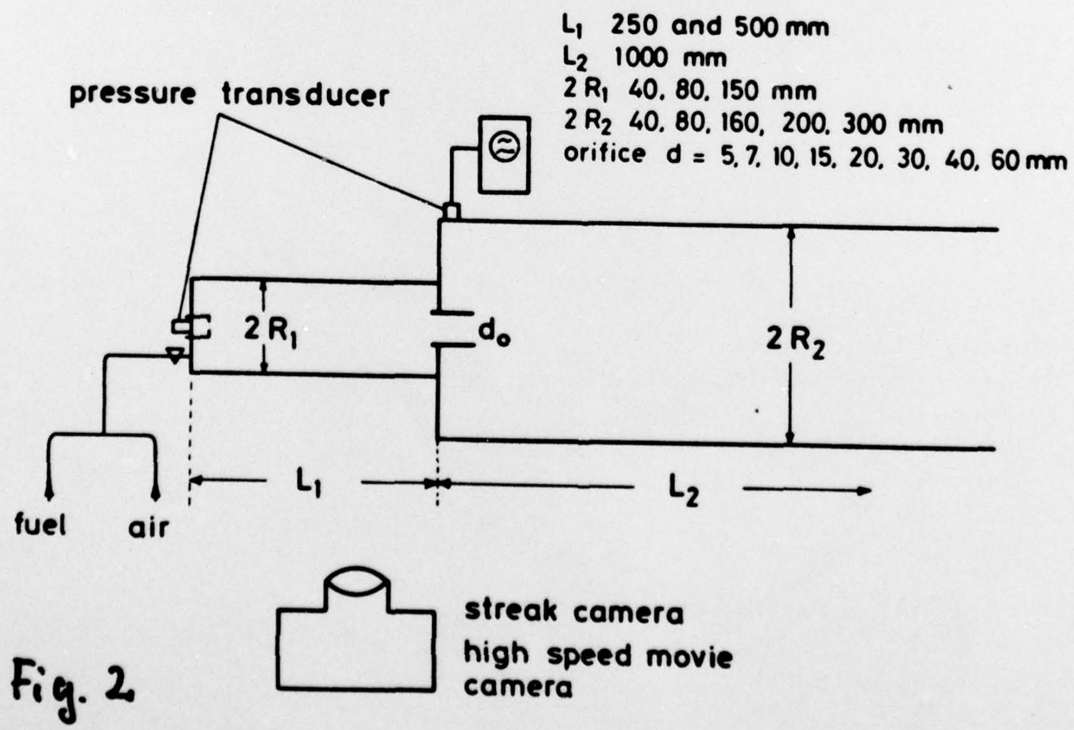
L1 250 and 500 mm
L2 1000 mm
2 R1 40, 80, 150 mm
2 R2 40, 80, 160, 200, 300 mm
orifice d = 5, 7, 10, 15, 20, 30, 40, 60 mm
pressure transducer
2 R1
d0
2 R2
L1
L2
fuel
air
streak camera
high speed movie camera

Fig. 2

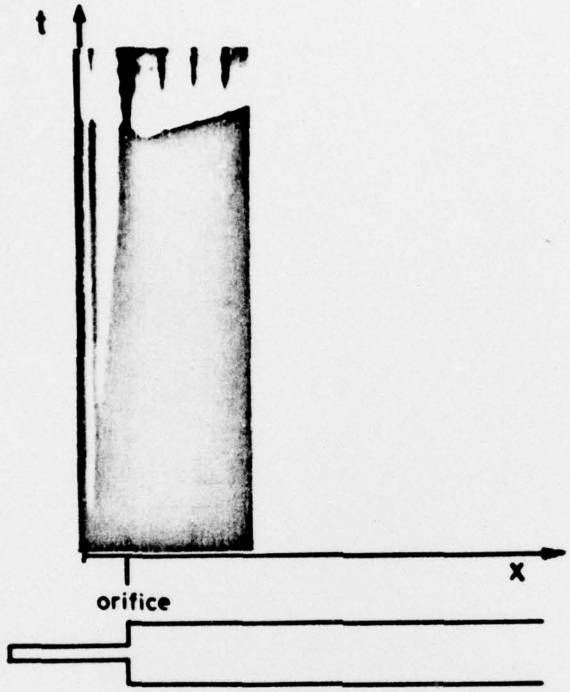
t
x
orifice

Fig. 3

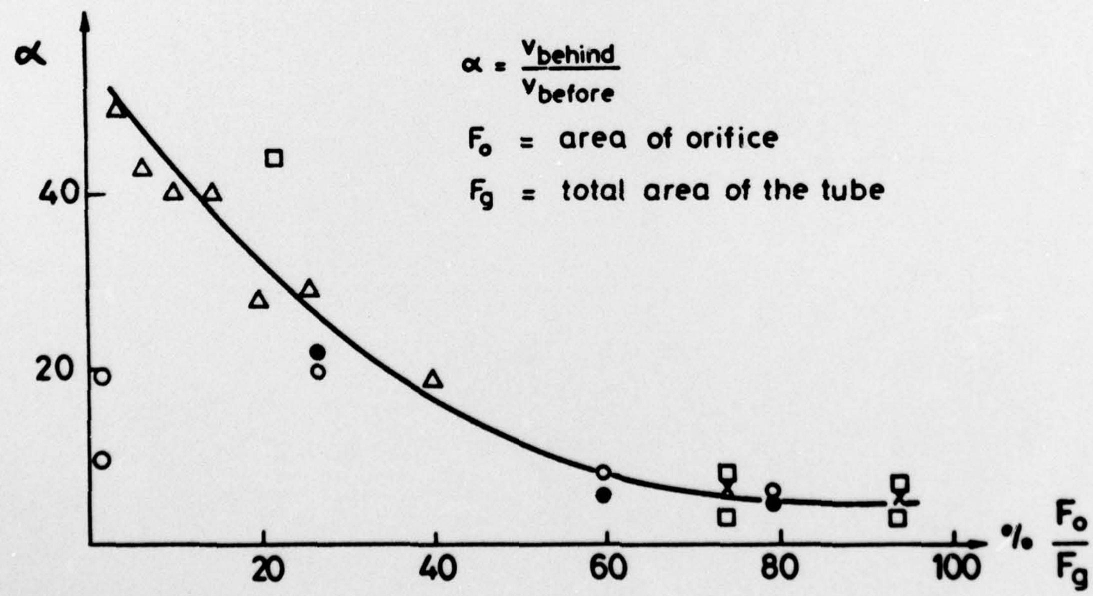
α
$\alpha = \frac{v_{behind}}{v_{before}}$
F_o = area of orifice
F_g = total area of the tube
40
20
20
40
60
80
100
% $\frac{F_o}{F_g}$

Fig. 4

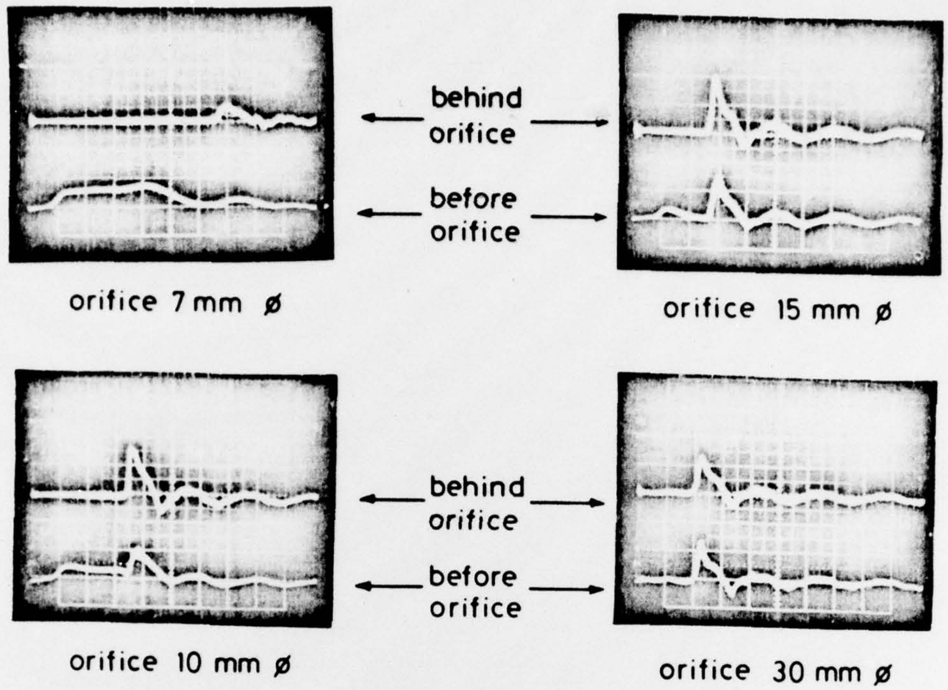
behind
orifice
before
orifice
orifice 7 mm ø
orifice 15 mm ø
behind
orifice
before
orifice
orifice 10 mm ø
orifice 30 mm ø

Fig. 5

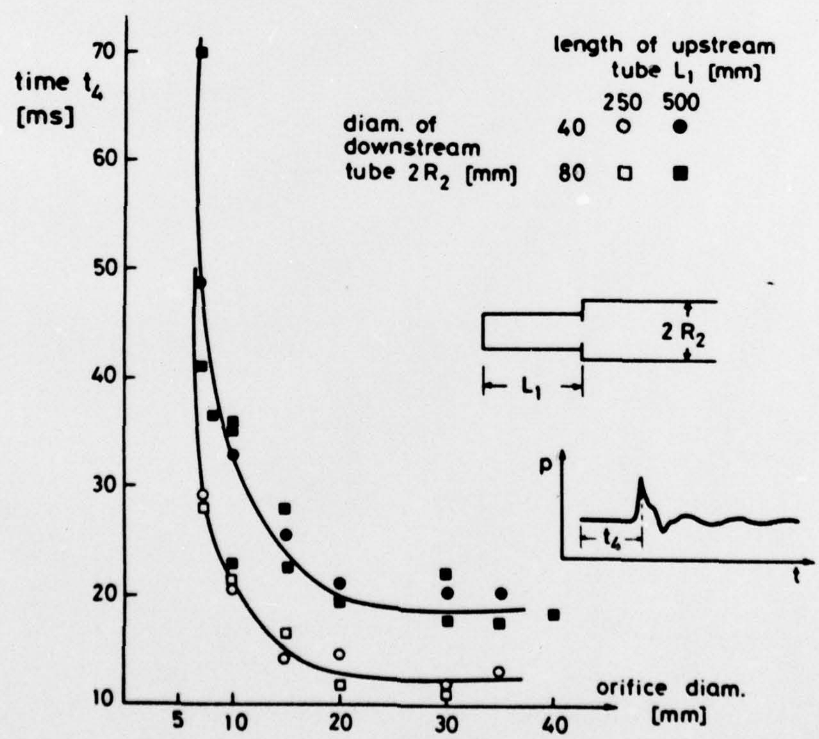
time t_4
[ms]
70
60
50
40
30
20
10
5
10
20
30
40
orifice diam.
[mm]
length of upstream
tube L_1 [mm]
250 500
diam. of
downstream
tube $2R_2$ [mm]
40
80
$2R_2$
L_1
p
t_4
t

Fig. 6

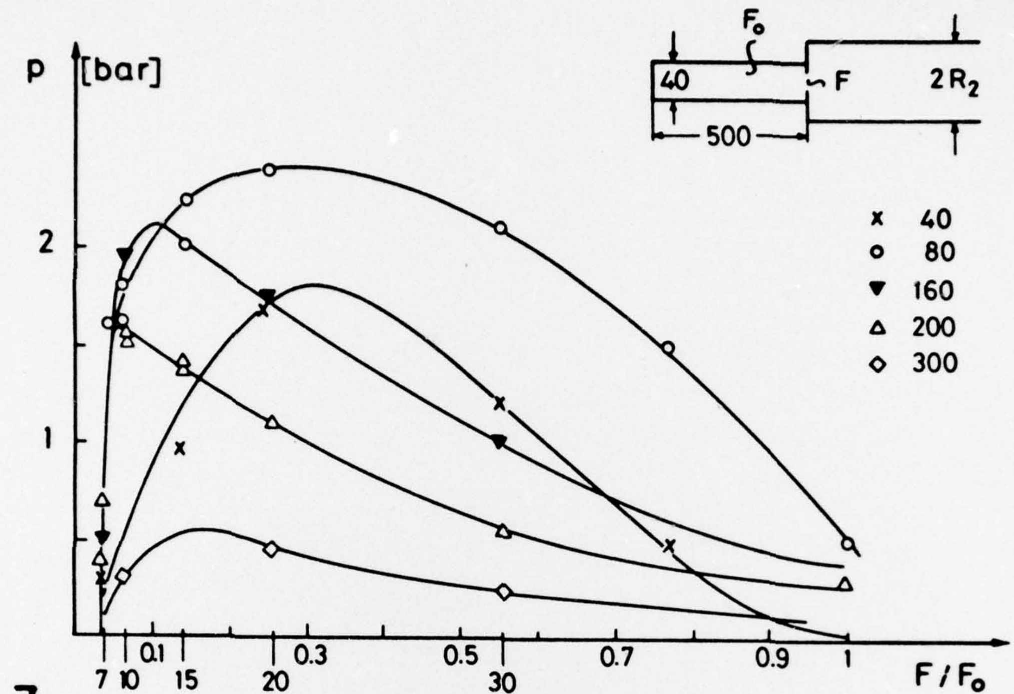
p [bar]
2
1
F_o
40
F
$2R_2$
500
x 40
o 80
▼ 160
△ 200
◇ 300
0.1
0.3
0.5
0.7
0.9
1
7
10
15
20
30
F/F_o

Fig 7

Fig. 8

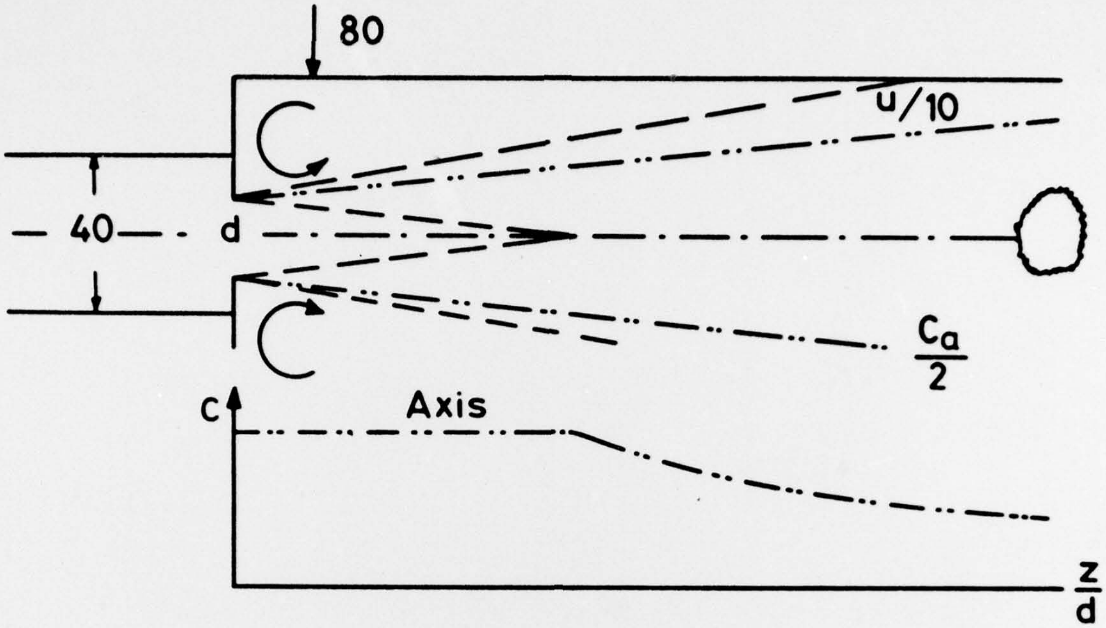

Fig. 9

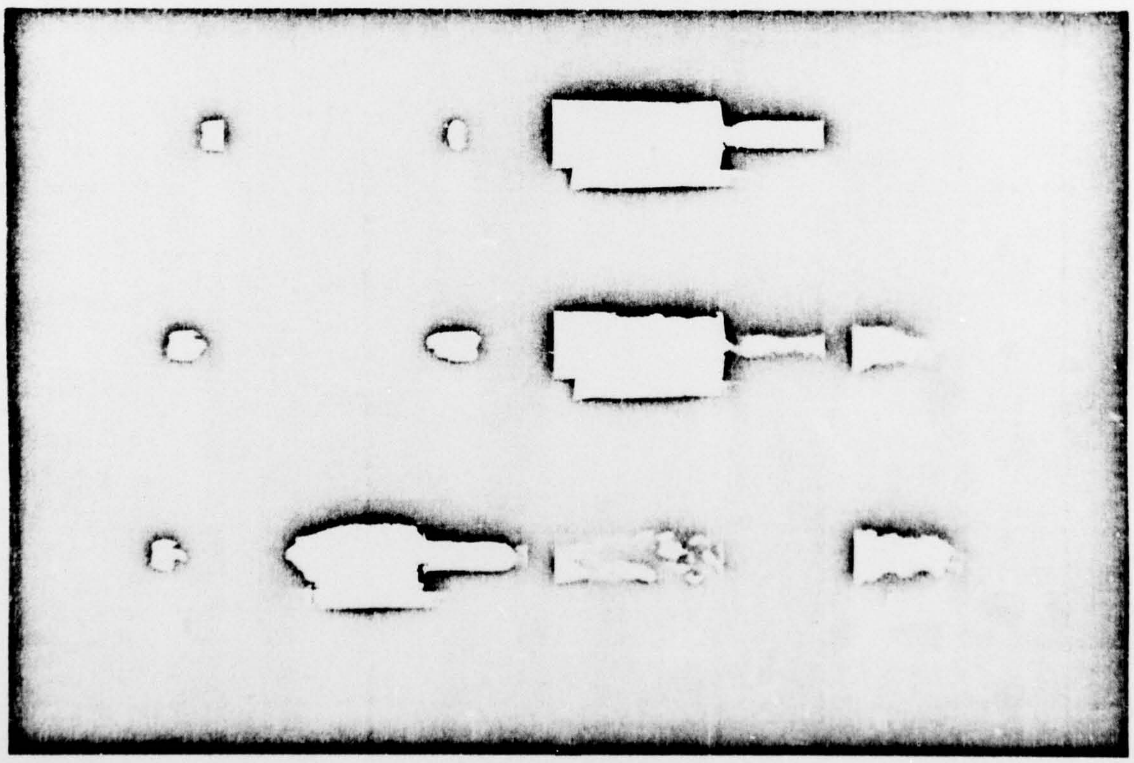

Fig. 10

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18 19 **REPORT DOCUMENTATION PAGE**

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1. REPORT NUMBER: AFOSR TR-77-1279

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

9

4. TITLE (and Subtitle)

6 INFLUENCE OF VARIOUS PARAMETERS ON INITIATION, STABILITY AND LIMITS OF DETONATIONS.

5. TYPE OF REPORT & PERIOD COVERED

INTERIM rept.
1 June 1976-31 May 1977

6. PERFORMING ORG. REPORT NUMBER

Report No 4

7. AUTHOR(s)

10 W. JOST
H. GEORGE WAGNER

8. CONTRACT OR GRANT NUMBER(s)

15 AFOSR-73-2541

9. PERFORMING ORGANIZATION NAME AND ADDRESS

UNIVERSITY OF GÖTTINGEN
INSTITUTE OF PHYSICAL CHEMISTRY, TAMMANNSTRASSE 6
34 GOTTINGEN, FEDERAL REPUBLIC OF GERMANY

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

16 2308A2
61102F 17 A2

11. CONTROLLING OFFICE NAME AND ADDRESS

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH/NA
BLDG 410
BOLLING AIR FORCE BASE, D C 20332

12. REPORT DATE

11 31 July 1977

13. NUMBER OF PAGES

13

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

12 14p.

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

14 SCIENTIFIC-4

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ACCELERATION OF SPHERICAL FLAMES
INFLUENCE OF ORIFICES IN THE FLAME PATH

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experiments on the influence of orifices on flame acceleration have been carried out with C_2H_4-air mictures in plexiglass ring metall tubes. Quantitative data could be obtained by pressure pickups and smear camera photographs.

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401 543

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